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Scenarios of Carbon Dioxide Emissions from Aviation

Karen Mayor[a] and Richard S.J. Tol[a,b,c,d]

Abstract: We use a model of international and domestic tourist numbers and flows to forecast tourist numbers and emissions from international tourism out to 2100. We find that between 2005 and 2100 international tourism grows by a factor of 12. Not only do people take more trips but these also increase in length. We find that the growth in tourism is mainly fuelled by an increase in trips from Asian countries. Emissions follow this growth pattern until 2060 when emissions per passenger-kilometre start to fall due to improvements in fuel efficiency. Forecasted emissions are also presented for the four SRES scenarios and maintain the same growth *pattern* but the *levels* of emissions differ substantially. We find that the forecasts are sensitive to the period to which the model is calibrated, the assumed rate of improvement in fuel efficiency and the imposed climate policy scenario.

Corresponding Authors: Karen.Mayor@esri.ie; Richard.Tol@esri.ie

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[a] Economic and Social Research Institute, Dublin, Ireland
[b] Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands
[c] Department of Spatial Economics, Vrije Universiteit, Amsterdam, The Netherlands
[d] Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA

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1. Introduction

Aviation emissions of carbon dioxide and other climate-changing substances have attracted substantial attention, particularly in Europe. Although the contribution of aviation to climate change is small, at just 3% of global emissions, it is growing (much) faster than other sources of emissions. Air travel has also long been seen as a luxury product, making it a popular target for environmentalists, who deem it unnecessary. Rising incomes and lower travel costs have resulted in a boom in air travel – a novelty among newly emerging economies characterised by large, fast growing and increasingly wealthy populations. The aviation industry is now also attracting the attention of policy-makers who endeavour to include it in climate policy. In this context, this paper presents scenarios of future tourist air travel and carbon dioxide emissions out to 2100. Only *international* aviation *demand* by *tourists* is examined. Business travel and domestic air travel are excluded. We will also look at how the flows and shares of tourists evolve from a geographical perspective. In a globalising world, identifying where the bulk of emissions from tourism come from at the moment and in the future is essential for designing comprehensive climate policy objectives.

Quantifying emissions from aviation entails data on travel patterns. The model used in this paper to forecast tourist air travel and carbon dioxide emissions from aviation is called the Hamburg Tourism Model (HTM) and is presented in Section 2. There are two other widely available and comprehensive sources of travel forecasts. The World Tourism Organisation (WTO) has developed a long-term forecast and assessment of the tourism industry up to 2020 called *Tourism 2020 Vision*. According to this forecast, international arrivals in 2020 are expected to reach 1.6 billion with Europe, East Asia and the Pacific, and the Americas being the top receiving regions.[1] This compares well with the 1.7 billion arrivals forecasted by HTM. This is the forecast produced when the model

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[1] http://www.unwto.org/facts/eng/vision.htm

is calibrated to match international arrivals in the 1995-2005 period instead of the full 1950-2005 period.

The World Travel and Tourism Council (WTTC) in conjunction with Oxford Economics also produces forecasts of tourist numbers. World forecasts for 2020 are about 2.8 billion international visitors.[2] HTM, when calibrated to match arrivals over 1950 to 2005, predicts approximately 2.6 billion arrivals. Hence, the predictions and figures used in this paper are broadly in line with other available forecasts.

The following section presents the model design and calibration. In section 3 we discuss the results of the analysis: the forecasts of carbon dioxide emissions and related variables such as trip length and tourist numbers. Emission forecasts by region are also examined. This is followed by a sensitivity analysis in section 4, which includes the application of different SRES scenarios, different climate change and policy assumptions as well as changes in the model specific assumptions such as fuel efficiency and the level of demand saturation for holidays. Finally, section 5 provides a discussion and conclusions.

2. The model

We use the Hamburg Tourism Model (HTM), version 1.4. Versions 1.0-1.2 were used to study the impact of climate change on international tourism (Hamilton *et al.*, 2005a,b; Bigano *et al.*, 2007a; Hamilton and Tol, 2007), while version 1.3 was designed to analyze climate policy (FitzGerald and Tol, 2007; Mayor and Tol, 2007; Tol, 2007), but also applied to the EU-US Open Skies Agreement (Mayor and Tol, 2008). Version 1.4 combines the two strands, uses the climate preferences as estimated by Bigano *et al.* (2006),[3] and is calibrated to a longer historical period.

HTM predicts the numbers of domestic and international tourists from 207 countries, and traces the international tourists to their destinations. Total tourism demand is driven by per capita income and population size. The demand for international tourism also

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[2] http://www.wttc.travel/eng/Tourism_Research/Tourism_Satellite_Accounting_Tool/index.php

[3] The general findings are that tourists prefer countries with a sunny yet mild climate and shun extreme weather, i.e. climates that are too hot and too cold.

depends on the size of the country and its climate. International destination choice is driven by per capita income and climate at the destination, and by travel time and cost.

More specifically, the basic data for the model are for the year 1995, the most recent year with reasonably complete data coverage. Data were primarily taken from the WTO (2003) and EuroMonitor (2002); see Bigano *et al.* (2007b). Behavioural relationships, estimated for 1995, were used to interpolate missing observations. Data are available on total numbers of tourists, international departures and international arrivals. The model was used to generate the 207x207 matrix of bilateral tourism flows. The model was calibrated such that the row and column totals of this matrix match the observations; the matrix itself is not observed.

The model runs in 5 year time periods from 1950 to 2100. Tourist numbers are calculated as perturbations of 1995. Total demand for tourism grows with per capita income, using an elasticity of 0.59. The total number of holidays is capped at 6 per year. The share of international trips in total holiday demand grows with per capita income, using an elasticity of 0.37. These elasticities were obtained by minimizing the squared relative distance between the model predictions of global tourism demand and the observations of WTO (2006) for 1950-2005. Climate also factors into the trade-off between domestic and foreign holidays. Tourists from countries with an average annual temperature of 18.6ºC are the least inclined to travel abroad. As the temperature gets warmer or colder, the desire to spend a holiday in a different climate grows.

The share of international trips in total holiday travel is capped from above by the size of the country, using an inverse logistic function with country area to the power of 0.61. Tourists from large countries are less like to travel abroad because the home country offers a more diverse range of holiday options. This cap is valid only for countries with an annual per capita income above $1,000. Very poor countries offer few holiday destination options, and the wealthy few who can afford holidays tend to travel abroad. The share of international holidays is capped from below by the size of the country, using an elasticity of -0.28, and per capita income, using an elasticity of -0.01. Again, holiday makers from very small and very poor countries take their vacations abroad. These parameters determine the frontier, and were set by minimizing the distance between the frontier and 1995 observations.

International tourists are allocated to their destination countries by four factors.[4] Per capita income is important, with an elasticity of 0.8, as poverty deters tourists. Climate is important too. The ideal annual average temperature is 16.2 ºC; colder and warmer destinations attract fewer tourists. Travel time and travel cost are not observed, and therefore assumed to be linear in the distance between airports, using data for Heathrow, Europe's busiest airport. The airfare elasticity of destination choice equals –1.50 +0.14ln$y$, where y is the average per capita income in the country of origin. For UK travellers, the elasticity equals –0.45, which compares well to the estimates of Oum *et al.* (1990), Crouch (1995), Witt and Witt (1995) and Wohlgemuth (1997). The time elasticity of travel is assumed to be -0.45 too, but is independent of per capita income. Travel costs are assumed to fall by 10% per five years, while the value of travel time is assumed to grow by 15%. These parameters follow from calibrating the model results to the regional observations of WTO (2006). The assumed parameters imply that travel becomes cheaper over time and people travel farther as a result. Furthermore, as people grow richer, the cost of travel matters less in their decision-making. However, as people take more and shorter holidays, travel time becomes more important.

Carbon dioxide emissions equal 6.5 kg C per passenger for take-off and landing, and 0.02 kg per passenger-kilometre (Pearce and Pearce, 2000). Emissions fall by 7.5% per five years, following the trend in fuel efficiency in Faber *et al.* (2007). No holidays at less than 500 km distance (one way) are assumed to be by air, and all holidays beyond 5000 km are assumed to be by air; in between the fraction increases linearly with distance. For island nations, the respective distances are 0 and 500 km. Total modelled emissions in 2000 are 129 million metric tonnes of carbon, which is some 2% of total emissions from fossil fuels. This is from tourism only. Total international aviation is responsible for some

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[4] There is also a calibration factor for 1995; essentially, all variables that are important to tourists but not explicitly listed (e.g., safety) are assumed to be constant at their 1995 values.

3% of global emissions.[5] There are no published numbers on the share of tourism in total international travel.

3. Basic results

Figure 1 shows the number of international arrivals by region for the period 1950-2005 as observed and as modelled. HTM clearly has difficulty in mimicking the historical period. Particularly in the last 15 years, tourism growth has decelerated while economic growth has accelerated. Table 1 illuminates this. Between 1950 and 2005, the total number of international tourists grew by 6.5% per year, while the population grew by 1.8% per year and per capita income by 2.1%. In 1950, 1/100 people holidayed abroad. In 2005, this was 12/100, a growth rate of 4.7%. This implies an income elasticity of 2.3. The bottom row of Table 1 shows the income elasticity per period. The period 2000-5 was very atypical. The income elasticity was at its lowest ever. SARS and geopolitical instability may have suppressed international holiday demand. HTM ignores this, and thus "predicts" that demand grows much faster. For future years, this implies that HTM assumes that tourism demand will catch up to its long-term trend. This is also the assumption used by the WTO in its forecasts for 2020.

Figure 2 shows the trend in future emissions, and decomposes this into its constituents – forecasted population, tourist numbers and trip characteristics are also shown. The future scenario is SRES B1 (Nakicenovic and Swart, 2001) as implemented by the IMAGE Team (2001), downscaled to the 207 countries of HTM. World population peaks at 9.5 bln in 2060, but this trend is swamped by the growth in tourism. By 2100, the model projects that the average number of holidays is 2.9 per person per year, 56% of which is taken abroad. That is, in 2100, the average person will go on holiday like the middle class in the OECD do today – much like nowadays that same middle class takes holidays in the same way the upper class did a century ago. As a result, international tourism grows by a factor of 12. The average trip length is projected to increase by a third. Although the demand for short holidays in the near abroad grows fast, the model foresees many once-in-a-lifetime holidays by Chinese and Indians in Europe and the USA. However,

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[5] See http://themes.eea.europa.eu/Environmental_issues/climate/indicators.

emissions per passenger-kilometre fall with improvements in fuel efficiency. The assumed rate of improvement in fuel efficiency is 1.5% per year. After 2060, this is the dominant force and emissions start to fall – but from a point almost 5 times higher as today's emissions.

Figure 3 attributes emissions to regions. In the short term, most of the growth in emissions from international tourism comes from East and Southeast Asia. In the medium term, South and Southwest Asia drive demand. In the long term, the rest of the currently lower income countries start travelling at a large scale, particularly South America, Central America and the Caribbean and Africa. The shares of emissions from different regions also change over the period. By the end of the century, Asia accounts for over 56% of world emissions while the share of emissions from the OECD falls from 42% in 2005 to 19% in 2100. The implications of this geographic shift are further discussed in Section 5.

The above results are all scenario- and model-specific. We therefore report sensitivity analyses below, which also help to understand the model dynamics.

4. Sensitivity analysis

This section presents sensitivity analyses relating to the SRES scenarios, as well as changes in the levels of demand saturation, fuel efficiency, climate change and climate policy and the calibration assumptions used. Figure 4 shows global emissions for the four main SRES scenarios. The main characteristics of these scenarios are as follows. The A1 scenario describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. The A2 scenario describes a very heterogeneous world. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more diverse and slower than in the other scenarios. The B1 scenario, our baseline, describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The B2 scenario describes a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 scenarios.

Despite the differences between the scenarios, the qualitative pattern is the same for tourism: initially rapid growth of emissions followed by a slowdown and a decline. Quantitatively, the scenarios differ considerably. The A2 scenario forecasts that emissions will grow to 400 mln tC in 2060 and stabilise thereafter, while the A1 scenario foresees 1000 mln tC of emissions in 2060. The B1 scenario, used as a baseline, lies somewhere in between. Table 2 compares aviation emissions to other emissions of carbon dioxide. In the A1 and B2 scenarios, aviation's contribution grows to some 6% of total CO_2 emissions from fossil fuel combustion. In the relative poor and industrialised A2 scenario, aviation contributes much less. However, the B1 scenario is not central in this regard at all. The contribution of aviation to total emissions grows to almost 12% as B1 is relatively rich and clean.

Figure 5 shows global emissions for a number of sensitivity analyses. In the "low saturation" graph, we assume that holiday demand saturates at four trips per person per year, instead of the six trips in the "baseline" scenario. The assumption, although highly uncertain and easily contested, has only a minor effect. This is because only a few countries reach their saturation point anyway.

In the baseline scenario, we assume that climate change has no effect on international tourism. Figure 5 shows the results with climate change, i.e. assuming the world warms to 3.1ºC above pre-industrial levels by 2100. The effect on emissions is minor, as the main impact of climate change is that people holiday elsewhere. However, the big travellers from rich, temperate countries (Germany, UK) seek holidays closer to home, and as total travel demand (in km) falls, so do emissions.

In the baseline scenario, we assume that there is no climate policy either. In Figure 5, we show the effect of a global carbon tax, starting at $10/tC in 2010 and rising at 5% per year. Initially, this has little effect because the price change is minor and the price elasticity is low. However, towards the end of century, the price effect becomes significant and this policy cuts emissions by 40% from the baseline.

The assumed rate of improvement in fuel efficiency is important. In the baseline, this is 1.5% per year. Figure 5 shows the effect of an increase to 2.0% per year (“accelerated technology” scenario). Peak emissions (2060) fall by 25%, and emissions in 2100 by 40% compared to the baseline scenario.

Finally, Figure 5 shows what happens if we calibrate the model to match international arrivals in the 1950-1995 and 1995-2005 periods, instead of the 1950-2005 period. As already indicated in Table 1, the growth rate of international tourism was particularly low between 1995 and 2005. Therefore, if we calibrate the model to the 1950-1995 period, emissions grow much faster and reach a peak that is almost twice as high. Because demand saturates earlier, emissions fall faster too in the second half of the century. If we calibrate the model to the 1995-2005 period, the historical record is not reproduced well, and the model foresees only a sluggish growth of international tourism and hence emissions. Emissions peak early, as India and China follow the US example and focus on domestic holidays after 2050.

5. Discussion and conclusion

We use a model of international flows of tourists to determine the effects of different growth scenarios on emissions arising from aviation. We find that international tourism grows by a factor of 12 between 2005 and 2100. This is due to fundamental changes in the number of trips being taken and in the origin of the tourists taking trips. Indeed, we find that gradually increasing incomes will lead to the average person being able to take more trips a year by the end of the century. The length of trips will also increase steadily. For the first part of the period, growth in East and Southeast Asia will be the driving force behind the growth in international tourism. This will expand to the rest of Asia in the medium term. In the later period of the forecasts, the growth in tourism will extend to South and Central America and Africa. As these currently lower income countries grow, higher proportions of their populations can afford to travel abroad.

These factors have natural repercussions for emissions from aviation, which grow by a factor of 4 between 2005 and 2060. This is less than expected due to improvements in fuel efficiency, which become significant from 2060 and lead to a fall in emissions. However, changes in the *structure* of international tourism affect the shares of emissions attributed to geographic regions. As a consequence, Asia accounts for over half of world emissions by 2100 replacing OECD countries as the main source of aviation emissions from tourism.

The sensitivity analyses shed light on the various outcomes that the scenarios presented can lead to. The SRES scenarios give varying forecasts depending on the growth scenario that is assumed. However, in order to get the full picture of possible outcomes, outside influences must also be taken into account. The climate policy scenario models the effect of a carbon tax. We find that the tax only has an effect on emissions when it is at a very high level. Similarly the effect of climate change is also minor causing a substitution in destinations rather than a reduction in trips.

Assumptions that do have an impact on forecasts and that would be worth investigating further are the holiday demand saturation level and the rate of improvement in fuel efficiency. The assumed saturation point for holiday demand has repercussions for future emissions as the absence of saturation could in theory lead to infinite tourist growth. However, in the time period examined in this paper this is not an issue as saturation is rarely reached. The assumed rate of improvement in fuel efficiency does affect the emission forecasts with the level of emissions falling compared to the base scenario. Fuel efficiency and technological progress reduce emissions per passenger-kilometre.

The change in the structure of tourism demand and in particular the origin of tourists in the future should be taken into account when formulating climate policy. As was shown, a carbon tax will only have an effect at a very high level and the effects of the tax on emissions in the short run will be eclipsed by the rise in demand for tourism, in particular from emerging economies. Any policy to curb emissions will have to take into account this new source of demand.

Acknowledgements

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Table 1. Total number of international tourists, population size, and per capita income, for the world, 1950-2005.

		1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005
Tourists	mln	26.5	43.8	73.0	118.6	174.3	233.7	292.3	336.5	461.9	568.2	722.2	848.0
Growth	%		10.6	10.7	10.2	8.0	6.0	4.6	2.9	6.5	4.2	4.9	3.3
Population	bln	2.694	2.951	3.241	3.583	3.972	4.383	4.787	5.224	5.700	6.158	6.612	7.038
Growth	%		1.8	1.9	2.0	2.1	2.0	1.8	1.8	1.8	1.6	1.4	1.3
Tour/pop	fraction	0.010	0.015	0.023	0.033	0.044	0.053	0.061	0.064	0.081	0.092	0.109	0.120
Growth	%		8.6	8.7	8.0	5.8	4.0	2.8	1.1	4.7	2.6	3.4	2.0
Income	$/cap	1864	2190	2455	2902	3420	3725	4119	4285	4667	4793	5171	5713
Growth	%		3.3	2.3	3.4	3.3	1.7	2.0	0.8	1.7	0.5	1.5	2.0
Elasticity			2.62	3.75	2.36	1.74	2.30	1.36	1.35	2.72	4.93	2.24	0.98

Table 2. Total emissions of carbon dioxide from fossil fuel combustion and aviation emissions (in billion metrics tonnes of carbon), and the share of aviation in total emissions (in percent) for the four SRES scenarios.

	A1			**A2**			**B1**			**B2**		
	Total	Aviation	Percent	Total	Aviation	Percent	Total	Aviation	Percent	Total	Aviation	Percent
2000	6.5	0.1	2.0	6.5	0.1	2.0	6.5	0.1	2.0	6.5	0.1	2.0
2020	12.1	0.4	3.7	11.0	0.3	2.4	10.0	0.4	3.9	9.0	0.4	4.3
2050	16.0	0.9	5.9	16.5	0.4	2.3	11.7	0.8	6.6	11.2	0.7	5.9
2100	13.1	0.8	5.9	28.9	0.4	1.4	5.2	0.6	11.8	13.8	0.6	4.4

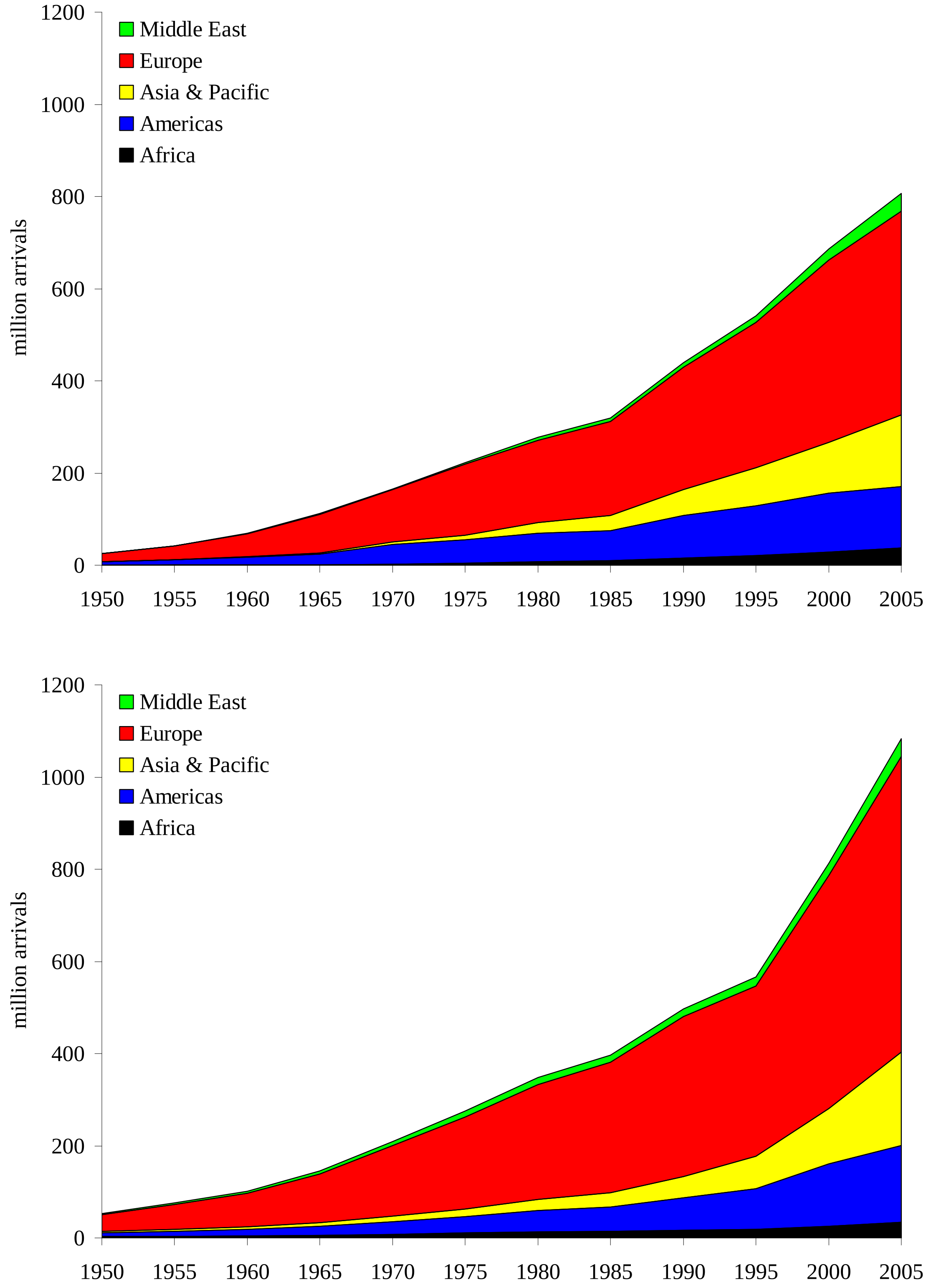

Figure 1. International arrivals by region for the period 1950-2005 as observed (top panel) and as modelled (bottom panel).

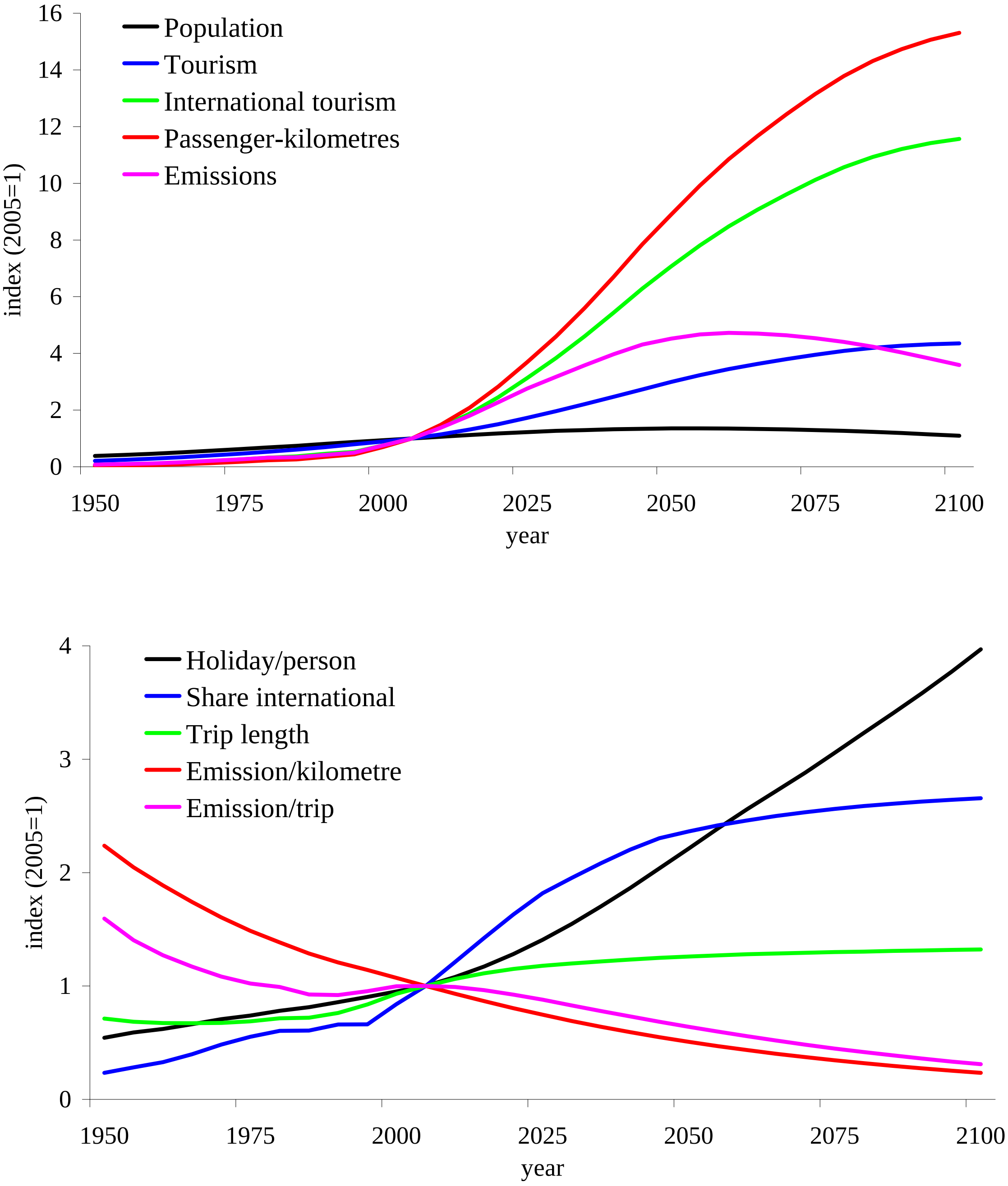

Figure 2. Population size, tourists, international tourists, kilometres flown, and carbon dioxide emitted (top panel) and average number of holidays per person, share of international in total holidays, average trip length, and average emissions per kilometre flown and trip (bottom panel), for the world, 1950-2100, indexed so that 2005=1.

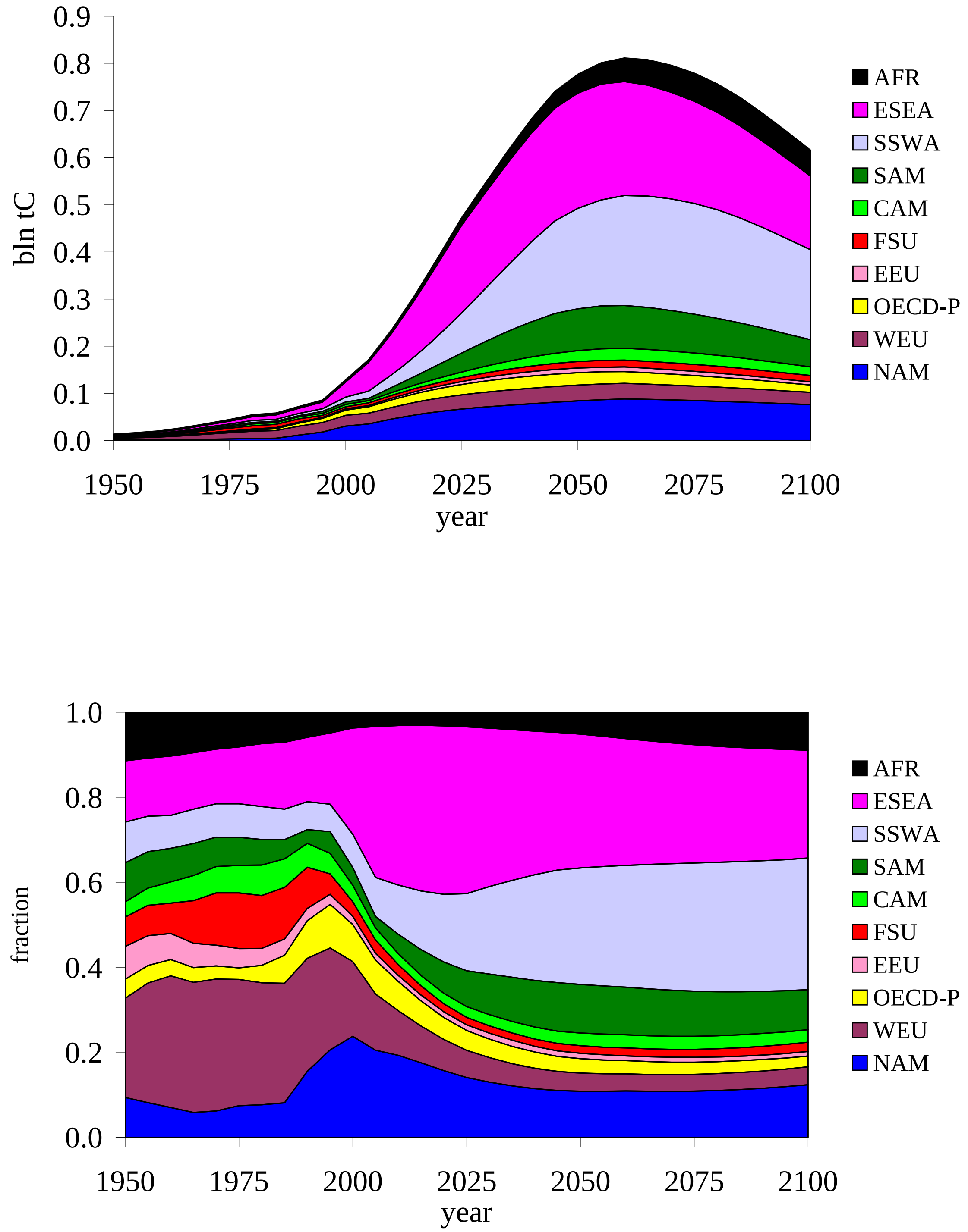

Figure 3. Carbon dioxide emissions (in billion metric tonnes of carbon) per regions (top panel) and as a share of world total (bottom panel), 1950-2005; AFR=Africa; ESEA=East and Southeast Asia; SSWA=South and Southwest Asia; SAM=South America; CAM=Central America and the Caribbean; FSU=former Soviet Union; EEU=Eastern Europe; OECD-P=Australia, Japan, New Zealand, and South Korea; WEU=Western Europe; NAM=North America.

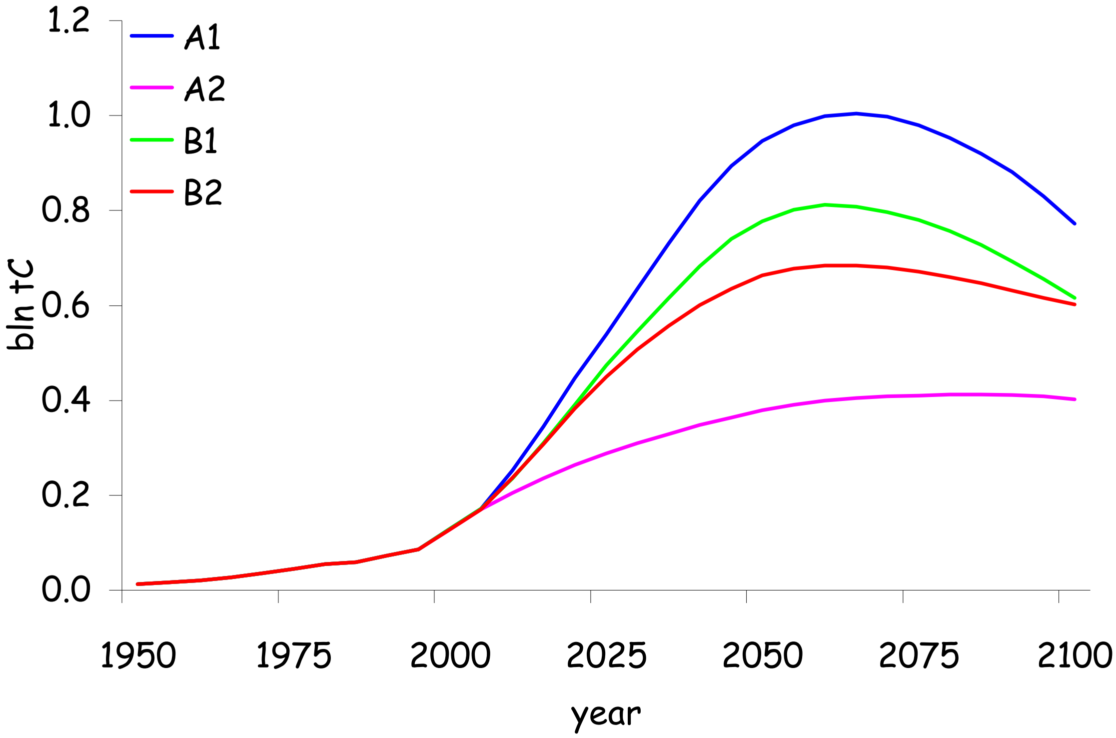

Figure 4. Global carbon dioxide emissions (in billion metric tonnes of carbon) from international tourism for the four alternative SRES scenarios, 1950-2100.

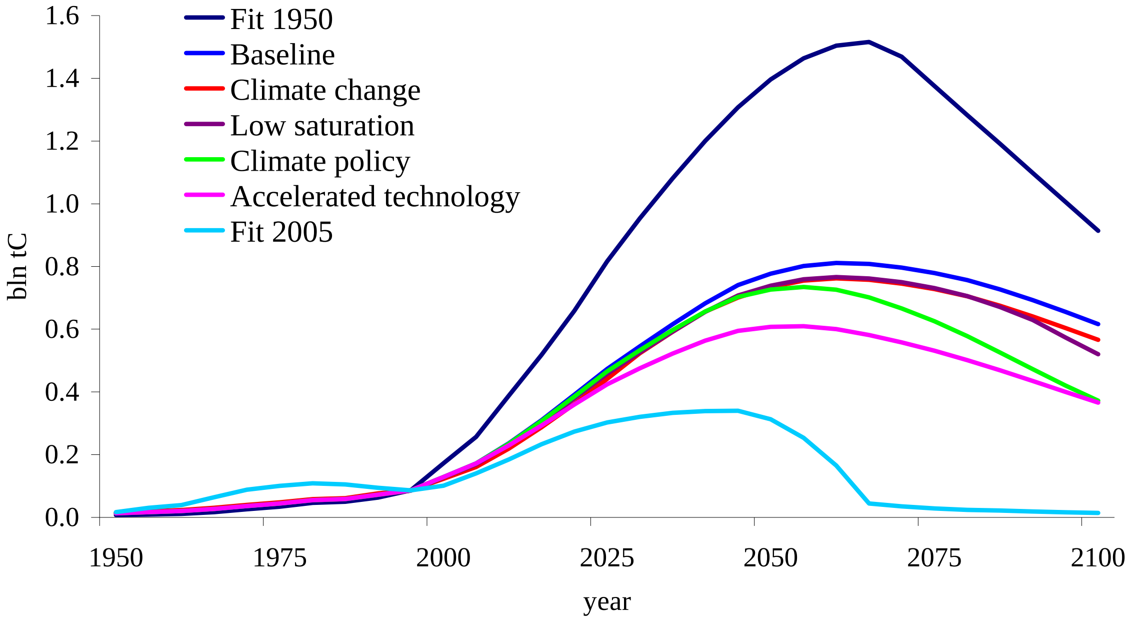

Figure 5. Global carbon dioxide emissions (in billion metric tonnes of carbon) from international tourism for a range of sensitivity analyses, 1950-2100.

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